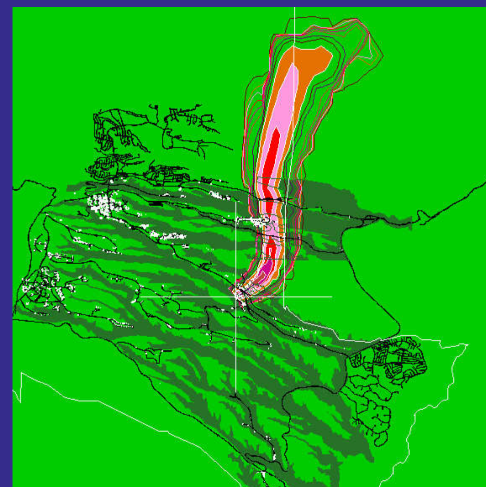
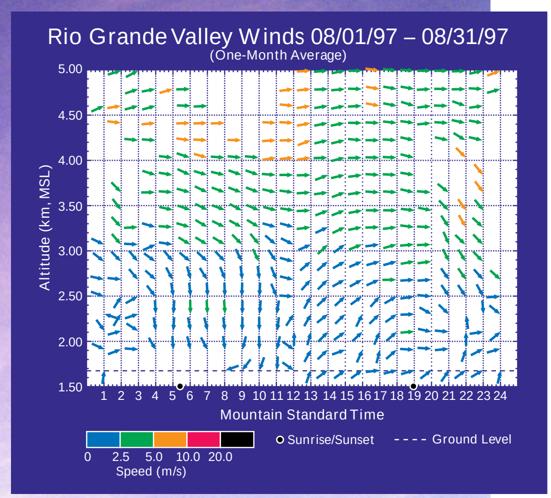
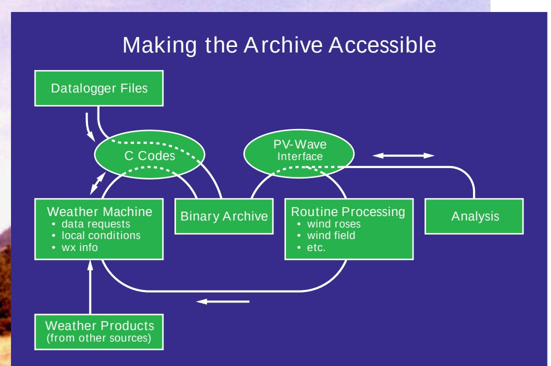
# Meteorological Monitoring at Los Alamos

*LA-UR-98-2148*
*May 1998*

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*Cover: The TA-6 meteorological tower is shown in the background photo. From top to bottom in the foreground: an example of output from a hypothetical release simulated by the R-MIDAS model, a time-height plot of monthly average winds in the Rio Grande Valley as measured by radar during a study with the Atmospheric and Climate Sciences Group (EES-8), and a flow chart depicting the flow of meteorological data from data logger files to end-user products.*

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*LA-UR-98-2148*
*Progress Report*

# *Meteorological Monitoring at Los Alamos*

## *Air Quality Group (ESH-17)*

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## PREFACE

“Meteorological Monitoring at Los Alamos” is Chapter 13 of the 1998 Los Alamos National Laboratory Environmental Monitoring Plan (EMP). The EMP is required by Department of Energy (DOE) Order 5400.1 (DOE 1990a), including an update every three years. This document supersedes “Meteorological Monitoring at Los Alamos” by Stone and Holt (1996), and is published separately from the EMP for ease of use and distribution by the meteorological monitoring program.

Chapter 13 describes all aspects of the meteorological monitoring program (referred to in this document as the “program”) as of April 1998. Additional information on the program can be obtained by calling (505) 667-7079 or by visiting the program’s World Wide Web site on the Internet at http://weather.lanl.gov.

## METEOROLOGY

The monitoring of meteorological variables at Los Alamos dates back to 1910, and these original records of maximum and minimum temperatures and precipitation are still archived by the program. The current meteorological monitoring program described here really began in 1979 with the installation of a tower network capable of performing the meteorological monitoring required of DOE facilities. A comprehensive climatology was compiled with data from this original tower network (Bowen 1990, 1992).

Significant improvements have been implemented since the inception of the early tower network. Some of the most recent improvements include substantial changes to the method of data archival and data access, the addition of a tower to the top of Pajarito Mountain, and work on several analysis projects.

The program can be divided into four main components: measurements, data management, analysis, and modeling. The measurement component sustains a continuous stream of high-quality meteorological data from the program’s extensive network of instruments. The data management component of the program maintains the quality, security, and accessibility of an extensive archive of data and displays products created from the data. The analysis portion of the program is conducted as time permits when requested by customers or when the program staff sees opportunities to increase knowledge of local weather phenomenon that could potentially affect operations at the Laboratory. The modeling component is conducted for the purpose of emergency response.

Years of collecting data have generated an extensive data base that is the basis of analyses and the source of input for local modeling. Data collected by the program also support other monitoring programs in biology, hydrology, and health physics and play a critical role in demonstrating regulatory compliance in the areas of air quality, water quality, and waste management.

Requests for data and analyses come from a wide variety of customers. The program’s Web page, the “Weather Machine” (http://weather.lanl.gov), services many of these requests with its data request forms and graphical and tabular displays.

## A. Rationale and Monitoring Requirements

Three DOE orders and guidance documents provide most of the rationale for the program: DOE Order 5400.1 (DOE 1990a); the "Environmental Regulatory Guide for Radiological Effluent Monitoring and Environmental Surveillance," DOE Order DOE/EH-0173T (DOE 1991a); and DOE Order 151.1 (DOE 1995), "Comprehensive Emergency Management System." Essentially, these orders state that DOE facilities are required to measure meteorological variables in sufficient detail to assess the impact of a release of hazardous material on the public and the environment. The three documents share some overlap for meteorology programs.

DOE Order 5400.1 requires a meteorological monitoring program, and it states that this program must be capable of determining whether the public and the environment are protected adequately during DOE operations. The program is required to meet high standards of quality and credibility. The design of the program is to be tailored to relevant local factors, including the effects of site topography, distance to receptors, and activities conducted at the facility. The program must fulfill all regulatory requirements and provide data needs for impact assessment, environmental surveillance, and emergency response. The order also requires that an EMP be developed and maintained.

The DOE publication DOE/EH 173T describes the elements of an acceptable effluent monitoring and environmental surveillance program at DOE sites. These elements include meeting data needs for emergency response, environmental surveillance, and impact assessment.

DOE Order 151.1 requires that capabilities be in place to adequately assess potential or actual on-site and off-site impacts of a release of hazardous material on the environment and on the public. This assessment should include a timely initial assessment of consequences, a continuous assessment of the emergency, integration of the consequence assessment process with other elements of emergency response, monitoring and evaluation of factors that may affect the emergency, and the capability of tracking and estimating the impact of hazardous materials on the public and environment.

Other DOE orders indirectly provide rationale for the program. For example, compliance with DOE Order 5400.5 (DOE 1990b), "Radiation Protection of the Public and the Environment," requires the Laboratory to perform modeling calculations that require meteorological data gathered by the program.

## B. Design Criteria

Los Alamos National Laboratory (LANL) is spread across 112 $km^2$ of the Pajarito Plateau in north-central New Mexico. The Pajarito Plateau slopes to the east-southeast, dropping 400 m across the Laboratory, with canyons and mesas running along the slope of the plateau. Vegetation varies from piñon/juniper at lower elevations to ponderosa pine forests found at higher elevations. Significant larger-scale topographic features also exist in the region. The broad Rio Grande Valley lies to the east of the Laboratory, and the Jemez Mountains, which extend up to around 900 m above the plateau, are to the west. These local and regional topographical features all contribute to the complexity of the site and significantly influence the local meteorology at the Laboratory.

Even though many hazardous materials are used at the Laboratory, most scenarios involving the release of these materials to the atmosphere do not pose a serious threat more than one or two km from the facility. However, under worst-case meteorological conditions, some releases could affect areas out to 10 km. The town of Los Alamos could potentially be affected by a release from a Technical Area (TA) 3 facility, particularly during the day when the prevailing wind direction is from the south at most towers. The town of White Rock, which lies to the southeast of the Laboratory, could be affected by a release during the nighttime when northwesterly drainage flows are common.

For climatological applications, stations located at the easternmost and westernmost edges of the Laboratory would be sufficient to capture the east-west gradient in precipitation and temperature caused by elevation and would be adequate for the formation of a wind climatology. However, calculating a wind field for real-time plume calculations in the Laboratory's complex terrain setting requires a more elaborate tower network. Because it is impractical to erect numerous towers, the problem then is to determine the appropriate number of towers that will sufficiently drive a wind field for plume modeling. Other restraints also play a role in siting the network. Fiscal restraints, availability of suitable measurement sites, locations of potential sources, and site complexity all influenced the design of the current network.

The current network includes four towers on the plateau, which are used to drive a simple, interpolated, diagnostic wind field, and a fifth tower is located in Los Alamos Canyon to give information on the larger canyons in the area. A sixth tower was recently installed on top of Pajarito Mountain to measure ambient conditions that can be used to predict wind shifts down on the plateau.

### *1. Monitoring Stations*

Meteorological monitoring stations, including a monostatic Doppler sound detection and ranging (sodar) system and three additional precipitation stations, are given in Table 13-1. The stations' location names, North American Datum (NAD) 27 state plane coordinates, and elevations are given.

**Table 13-1.** Meteorological Observing Stations

| | Station Name | Alternate Name(s) | LANL Structure Number | NAD 27 State Plane Coordinates (ft) | | Elevation (ft) z |
|---|---|---|---|---|---|---|
| | | | | x | y | |
| **Towers** | TA-6 | none | TA-06-0078 | 479551 | 1768778 | 7424 |
| | TA-41 | Los Alamos Canyon | TA-41-0064 | 486411 | 1774221 | 6914 |
| | TA-49 | Bandelier | TA-49-0123 | 485526 | 1751324 | 7045 |
| | TA-53 | LANSCE | TA-53-1020 | 498898 | 1771933 | 6990 |
| | TA-54 | TA-54 / White Rock | TA-54-0088 | 508065 | 1755793 | 6548 |

*Continued on next page*

**Table 13-1—*Continued***

| | Station Name | Alternate Name(s) | LANL Structure Number | NAD 27 State Plane Coordinates (ft) | | Elevation (ft) z |
|---|---|---|---|---|---|---|
| | | | | x | y | |
| **Towers** | Pajarito Mountain | none | none | 457098 | 1777903 | 10360 |
| **Sodar** | Sodar | none | TA-06-0100 | 479806 | 1768778 | 7417 |
| **Precipitation** | TA-16 | S-Site | TA-16-0209 | 469107 | 1762277 | 7635 |
| | TA-74 | White Rock Y, Test Well 1, Pueblo Canyon | none | 509840 | 1772061 | 6370 |
| | North Community | North Area | none | 478950 | 1783110 | 7420 |

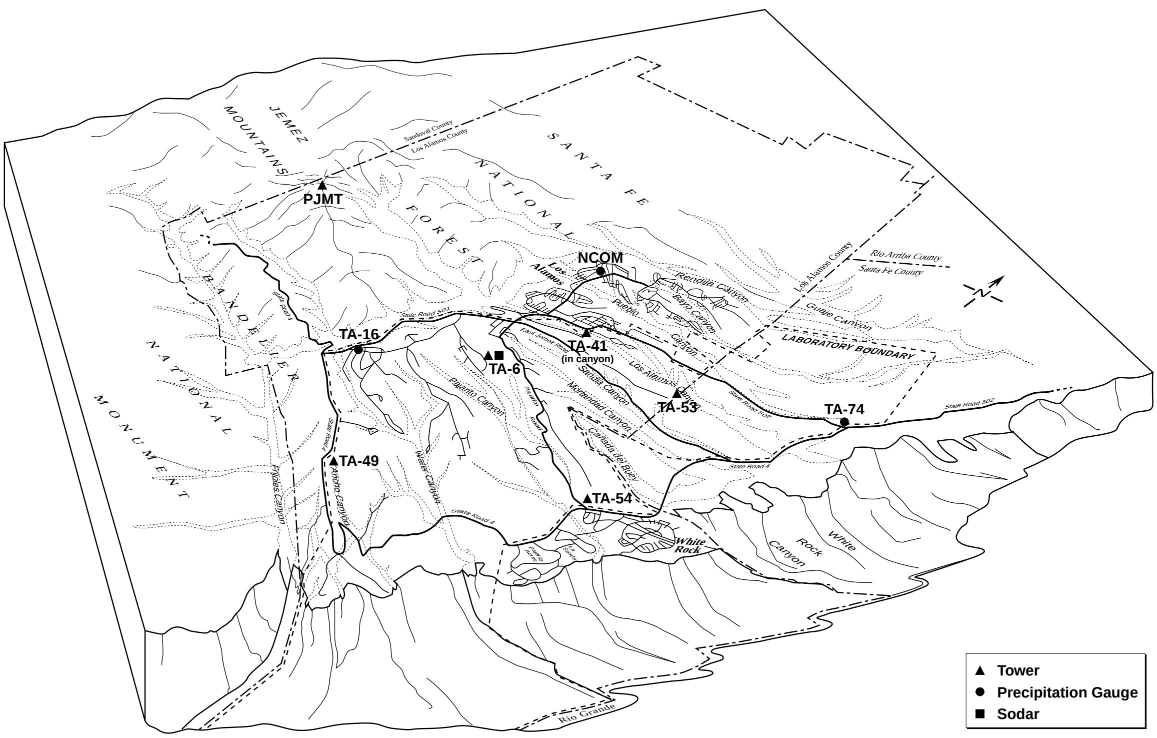


**Figure 13-1.** Map showing locations of meteorological observing stations.

Spacing between the towers is relatively even with a mean distance of seven km. Below is a brief description of the towers:

- The **TA-6 tower** is 92 m tall and instrumented at five levels. It is located on the Pajarito Plateau in a natural meadow site that tilts about 1.5˚ to the east-southeast. The fetch within several hundred meters of the tower is over short grasses and widely scattered low shrubs. The tower is tall enough to characterize the azimuthal shear often present at night, but it is too short to see azimuthal shear that often occurs above the 200- to 500-m-deep upslope flow during the morning hours.

  This station is the official meteorological station for Los Alamos and the Laboratory; observations from this site are reported to Cooperative Observer Network of the National Weather Service (NWS) and are archived at the National Climatic Data Center (NCDC). Climate statistics for the upper Pajarito Plateau are compiled from observations at this site.

- The **TA-6 sodar** is located 78 m east of the tower. This location is considered a good site acoustically because of the low noise level. The sodar provides information on winds from the Pajarito Plateau up to the height of the local mountain tops, and these observations have been used to characterize upper level winds for explosives shots.

- The **TA-41 tower** is 23 m tall and instrumented at three levels. It is located in Los Alamos Canyon where the canyon is approximately 100 m deep and 300 m wide. Observations from this tower indicate whether airborne material is likely to travel up- or down-canyon or be caught up in a rotor inside the canyon.

- The **TA-49 tower** is 46 m tall and instrumented at four levels. It is located on the Pajarito Plateau in an open meadow. Fetch within several hundred meters is over short grasses. The meadow site tilts 2˚ to the east-southeast. The tower is located near a transmissometer station operated by Bandelier National Monument and close to technical areas where high-explosive experiments are conducted. The tower is also used to characterize wind conditions at the old tritium facility at TA-33.

- The **TA-53 tower** is 46 m high and instrumented at four levels. It is located on the narrow mesa between Sandia and Los Alamos Canyons. It is east-northeast of the Los Alamos Neutron Science Center (LANSCE) stack, which is the Laboratory's largest routine emitter of radionuclides. This tower also characterizes wind conditions around TA-21.

- The **TA-54 tower** is 46 m tall and instrumented at four levels. It is located in a clearing in piñon/juniper woodland at the eastern edge of Mesita del Buey, an area where low-level radioactive wastes and mixed chemical wastes are handled and stored. Measurements from the TA-54 tower are used in environmental performance assessments of the waste site and would be used to characterize atmospheric transport and dispersion in the event of a release from operations at TA-54.

- The **Pajarito Mountain tower** is 36 m tall and instrumented at two levels. It is located on top of Pajarito Mountain near the top of the Aspen chair lift at the Pajarito Mountain ski hill at an elevation of 3159 m (10,360 ft) or approximately 900 m above the Pajarito Plateau. The tower is actually a cellular phone tower, and instrumentation has been placed on top of the tower. This site gives approximate ambient wind conditions that can be used to predict winds on the plateau.

The precipitation network consists of seven stations, all with automatic data acquisition. Four of these stations are collocated with the tower stations; the three additional sites are listed below:

- The **North Community station** is on the roof of the volunteer fire department's building at 4017 Arkansas. The building is approximately 12.2 m tall. This station is used to determine precipitation along the northwestern edge of the Laboratory site.
- The **TA-74 station** is next to Test Well 1 in Pueblo Canyon. This station characterizes precipitation along the eastern edge of the Laboratory site.
- The **TA-16 station** is on the roof building 209 approximately 3.7 m above grade. This station is used to determine precipitation along the western edge of the Laboratory site.

### *2. Adequacy of the Tower Network*

A study by Lee et al. (1994) attempted to determine the adequacy of the current tower network. The study modeled hypothetical particle trajectories from the Chemistry and Metallurgy Research (CMR) building at TA-3, using a $1/r^2$ interpolated wind field driven by data from the current tower network. The method for calculating the wind field mimics the program's current modeling capability. The particle trajectories from the four-tower network were then compared with trajectories using a wind field driven by data from the four-tower network and an additional temporary tower erected north of the Los Alamos town site.

The method used in the study was to calculate a pair of particle trajectories for all northbound trajectories from five months of data. One trajectory relied on the wind field calculated from the four-tower network, and one relied on the wind field calculated from the five-tower network. Statistics concerning the difference between the two trajectories at 2, 4, 6, and 8 km from the source were then compiled. Figure 13-2 shows three of the particle trajectories. The four-tower trajectories are shown as the solid lines, and the five-tower trajectories are given as dashed lines. The additional station is shown on the map labeled "golf."

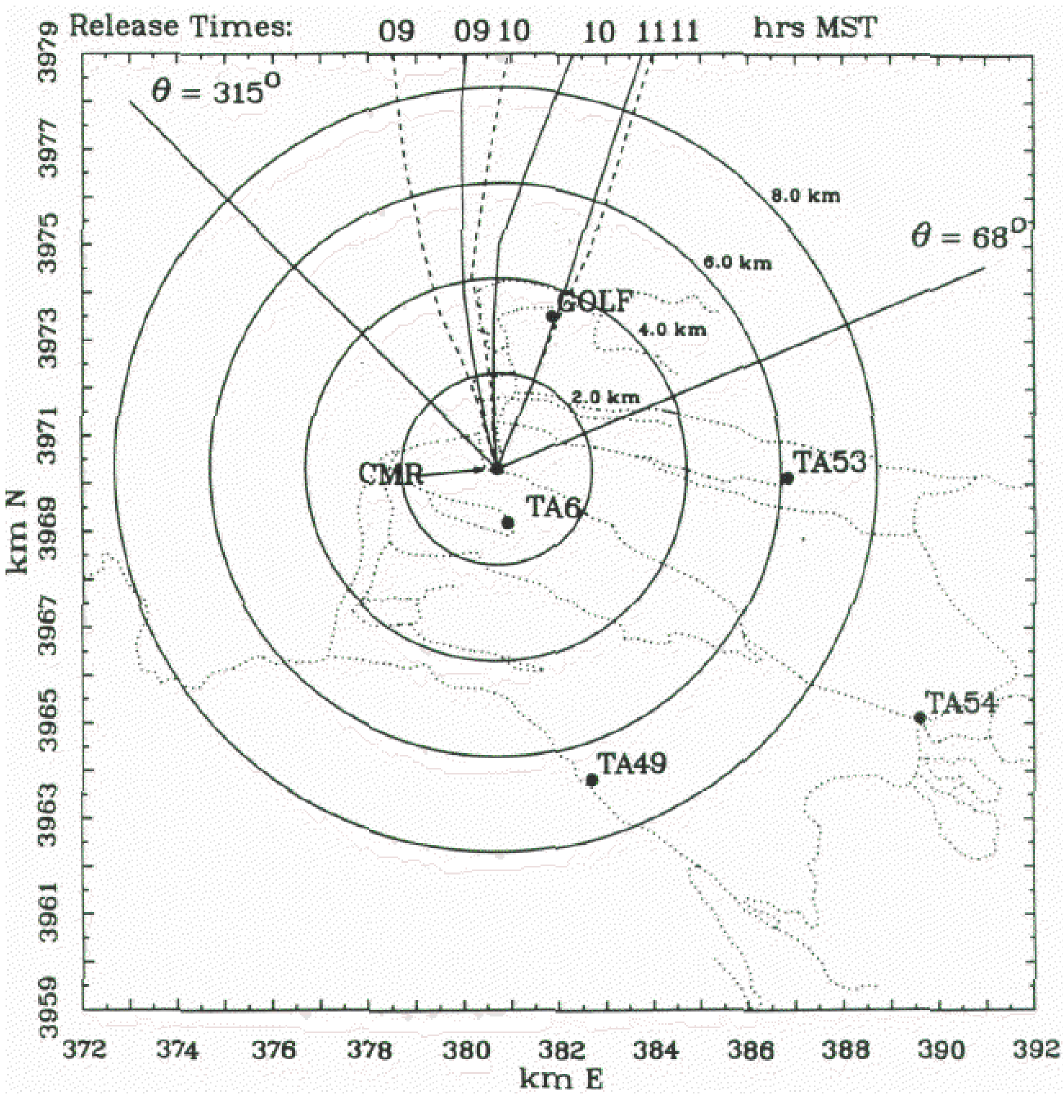


**Figure 13-2.** Three example pairs of trajectories used in the study by Lee et al. (1994). Trajectories shown as solid lines are based on data from the existing four plateau towers. Dashed trajectories are obtained when data from a fifth tower, marked “golf” on the map, is added to the calculation.

Figure 13-3 shows a histogram and a cumulative frequency distribution for the separation between the particles at 4 km from the source. These plots show that errors in the plume location, using the program’s current modeling scheme, will be less than or equal to 0.35 km 50% of the time, and less than or equal to 1.1 km 90% of the time.

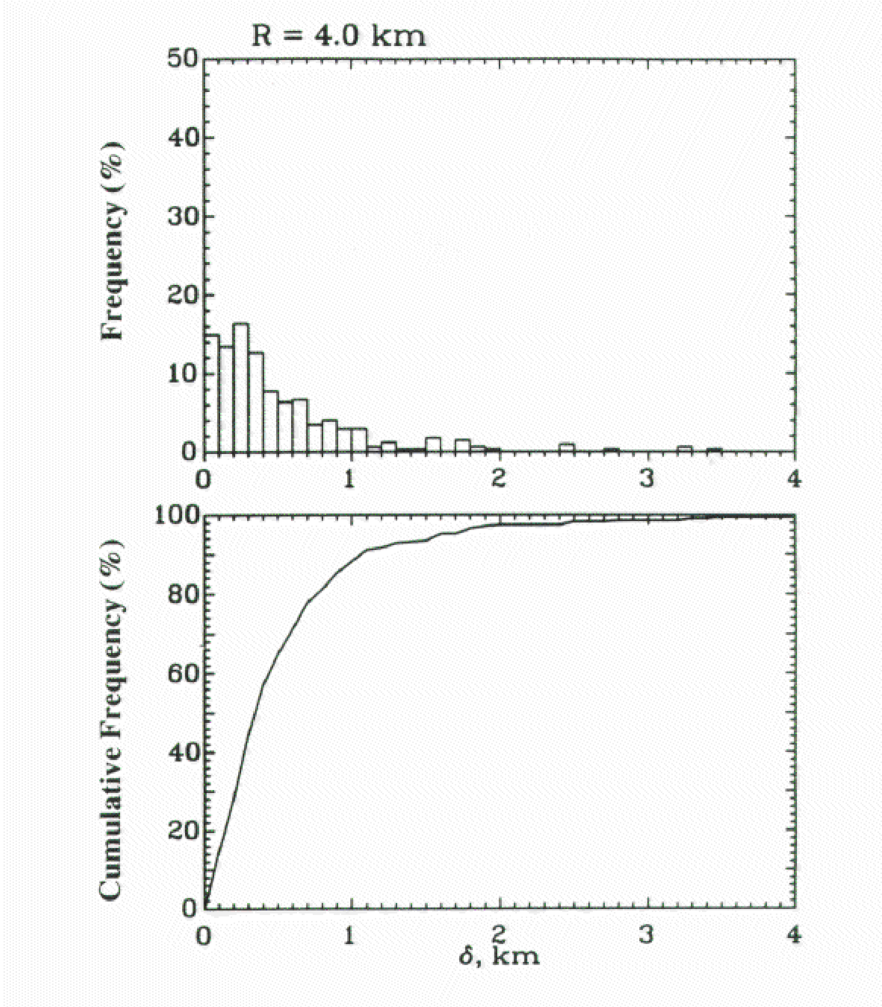


**Figure 13-3.** Histogram (top) and cumulative frequency distribution (bottom) for the separation, $\delta$, between trajectories at 4 km from the source.

The conclusion from the study was that the benefits of adding an additional tower north of the town of Los Alamos would not significantly improve plume modeling. Evacuation decisions by emergency managers would be carried out for entire neighborhoods of Los Alamos, so the additional detail gained from the five-tower network would not change the response strategy.

## C. Program Implementation

### *1. Measurements*

#### a. Instrumentation

High quality meteorological measurements are the foundation of the program. The objective is to deliver a continuous stream of data with a recovery of at least 95% (for in situ measurements). Program measurements meet or exceed recommendations found in EPA 1987, EPA 1989, NWS 1989, and EPA 1981.

Over 100 instruments, consisting of over 20 different types of sensors, are used in the network. All instruments are of high quality and are purchased from reputable manufacturers. The entire network undergoes calibration inspections twice a year, and all test equipment and calibration standards are traceable to the National Institute of Standards and Technology (NIST). An external audit is performed every two or three years and takes the place of one of the internal calibration inspections. The types of instruments used in the network are given in Table 13-2.

**Table 13-2.** Instruments Used Throughout the Network

| Variable | Instrument Type | Number Used |
|---|---|---|
| Wind variables | | |
| $u$ | Propeller-driven DC tachometer | 16 |
| $u$ | Sonic anemometer | 2 |
| $\theta$ | Vane-driven potentiometer | 16 |
| $w$ | Propeller-driven DC tachometer | 14 |
| $w$ | Sonic anemometer | 2 |
| $u_s$, $\theta_s$, $w_s$ | Monostatic Doppler acoustic sounder (sodar) | 1 |
| Atmospheric state variables | | |
| $T$ | Thermistor (aspirated) | 21 |
| $T$ | Thermocouple | 2 |
| $p$ | Variable ceramic capacitor | 3 |
| $h$ | Hygroscopic capacitor | 5 |
| $q$ | Infrared optical hygrometer | 2 |
| Precipitation variables | | |
| $r$ | Heated tipping bucket with wind screen | 9 |
| $s_d$ | Ultrasonic measurement of distance to snow surface | 2 |
| $l$ | Optical and rf sensors | 1 |
| Radiative fluxes | | |
| $K\downarrow$ | Pyranometer (aspirated) | 5 |
| $K\uparrow$ | Pyranometer | 2 |
| $L\downarrow$ | Pyrgeometer (aspirated) | 2 |
| $L\uparrow$ | Pyrgeometer | 2 |
| Subsurface measurements | | |
| $T_s$ | Thermistor | 10 |
| $Q_g$ | Thermopile | 4 |
| $\chi_w$ | Time domain reflectometer | 4 |
| Fuel moisture | | |
| $W_{10}$ | Capacitance of wood dowel | 1 |

In general, instruments in the network operate continuously under local weather conditions. Occasionally snowstorms cause icing on wind instruments and upward-facing radiometers, and lightning strikes to towers can cause damage to instruments. Considerable attention has been given to lightning protection however, and although the Los Alamos area has one of the highest flash densities of lightning in the United States, data loss caused by lightning strikes is rare.

All wind instruments are supported by towers of an open-lattice construction with instruments mounted on booms. To reduce flow distortion from the tower, booms face westward into the prevailing wind direction and are twice the tower width. The booms are attached to an elevator that can be lowered for instrumentation inspection. Booms are not used for the Pajarito Mountain tower, which has its instrumentation situated on the top of an open-lattice, 36 m, cellular phone tower. Towers, guy lines, and elevators are inspected periodically by a licensed tower erection contractor for wear and safe operation. Results of the last inspection are discussed in Tower Systems, Inc. 1997.

**b. Observed Variables**

Meteorological variables measured by the program can be grouped into the categories of wind, sodar-derived wind, atmospheric state, precipitation-related, radiative fluxes, eddy heat fluxes, subsurface measurements, and fuel moisture. Below is a brief description of each category, including its importance to the program.

- *Wind variables*. The tower network provides continuous measurements of mean wind speed, wind direction, and turbulence at multiple levels over the Pajarito Plateau, on top of Pajarito Mountain, and in Los Alamos Canyon. These data are critical to emergency preparedness, dose modeling for regulatory compliance, and planning studies.

- *Sodar-derived wind variables*. Under ideal conditions, the sodar shows winds from the plateau up to near the level of the Pajarito Mountain tower. Because the sodar is the only instrument in the network that can measure azimuthal shear over a deep layer of the atmosphere, it is critical for alerting the staff to potential wind direction changes (or possible changes in a plume's trajectory). The sodar also can provide time-height plots of echo strength from the vertically directed antenna. In a preliminary study, these data were seen to provide an estimate of the mixing height (Baars 1997), which can be an important parameter in plume modeling under certain conditions.

- *Atmospheric state variables*. Continuous measurements of temperature, pressure, and moisture variables are used to document the state of the atmosphere. Temperature applies to a wide range of planning studies and documentation, and it is one of the inputs to the evaporation algorithm for chemical plume modeling. Pressure is used to calibrate several other environmental measurements and to calculate the potential temperature lapse rate. Atmospheric moisture variables are used in engineering design, estimates of evapotranspiration, and forecasting.

- *Precipitation-related variables*. One of the most frequently requested data types is precipitation data. It is used by biologists, hydrologists, and those involved with regulatory compliance, and it is an input to the washout algorithm for modeling radioactive plumes. Snowfall and snow depth measurements are reported to the NWS and the NCDC and are used for various forms of documentation.

  The lightning data represent the number of strokes detected in a given period over a range that depends on sky conditions and the natural variation in lightning flashes (estimated to be 5 km to 50 km). Lightning stroke rate is a sensitive indicator of the electrical power generated by a thunderstorm, and this power is closely related to the severity of the weather (wind, hail, and rain) associated with the storm. Because the lightning detector is capable of detecting intracloud lightning, which usually precedes the more dangerous cloud-to-ground lightning by 10 to 30 min, it has some early warning potential. Also, the occurrence of dry thunderstorms can be detected by identifying times when lightning is detected but no precipitation is measured. Dry thunderstorms have the potential for igniting wildfires which is a concern of fire managers.

- *Radiative fluxes*. Short-wave and long-wave irradiances are used to estimate the net radiative forcing at the surface, which is important in the surface energy balance. The downward short-wave irradiance is used to estimate atmospheric stability, calculate evaporation, and document sky conditions for experiments. The upward short-wave irradiance provides information on the condition of the surface, or the albedo, such as determination of snow cover or ground wetness, which is also used in experiments. The downward long-wave irradiance provides cloud cover information at night.
- *Eddy heat fluxes*. Eddy heat fluxes describe how the net radiative forcing at the surface is dissipated. Latent heat flux is related to evapotranspiration, which is being used by a number of environmental scientists, including hydrologists interested in calculating the water budget for the area.
- *Subsurface measurements*. Measurements of soil temperature, soil moisture, and ground heat flux represent an attempt to document the response of the upper layers of the soil to atmospheric forcing. The ground heat flux completes the surface energy balance, which in turn allows for quality control of the eddy flux measurements. The subsurface measurements have recently been modified in hopes of improving the measurement of the ground heat flux. These modifications include adding the measurement of soil moisture, spatial averaging of soil temperature, and the addition of two measurement levels. The extent to which these measurements improve the ground heat flux measurement is under study.
- *Fuel moisture*. Measurement of the fine-dead fuel moisture was recently added to the network to fulfill a demand that the program aid in determinating the local fire danger. Fine-dead fuel moisture is an important quantity in assessing various aspects of the local fire danger. The 10-hr fuel moisture is measured, and a modified National Fire Danger Rating System (NFDRS) algorithm is then used to estimate the 1-hr fuel moisture.

Table 13-3, parts (a) through (h), define all the meteorological variables measured or computed across the network. The tables are organized into sections corresponding to variable type: wind, atmospheric state, precipitation related, radiative energy fluxes, eddy heat fluxes, subsurface measurements, and fuel moisture. Because the sodar is a remote sensing system and because it has not yet been fully integrated into the program’s data management scheme, it is treated separately. Variables obtained from this system are shown in Table 13-4.

Symbols given in the first column of Tables 13-3 (a)–(h) and 13-4 are conventionally used in meteorological literature and are standard in program documentation. Symbols on the left side of the first column denote the primary variables, which are those obtained from an appropriately conditioned signal from an instrument’s transducer. Indented symbols in the first column represent variables that are calculated, usually from the primary signal. In a few cases (for example, dew-point temperature) these variables are calculated from multiple signals.

The second column shows the variable names used in locally developed data processing software. The *z* character in variable names refers to the level at which the measurement is made.

The third column gives the units of measurement for the given variables. These are generally standard SI units although exceptions are found (for example, millibars are used instead of Pascals for pressure).

The variables are defined in the fourth column. Unless otherwise noted, variables are based on a 15-min sampling period. The integral means that the integrand has been integrated from 0000–2400 Mountain Standard Time (MST). Resolution of the archived data and estimated accuracy are given in parentheses. For example, (0.1, ±0.3˚C) means that the data are archived to the nearest 0.1˚C and the accuracy is estimated at ±0.3˚C. When the accuracy is undetermined, two asterisks (**) are inserted. Accuracy estimates are based on instrument accuracy as stated by the manufacturer, adjusted to reflect uncertainties in instrument alignment, exposure, and filtering and sampling effects, when appropriate.

**Table 13-3**. Symbols, Variable Names, Units, and Definitions

**Part (a) Time Variables**

| Symbol | Variable Name | Variable Definition |
|---|---|---|
| | doy | Day of year (1 to 365 or 366) |
| $t$ | time | Mountain Standard Time (1, ±1 min) |
| | year | Year |

**Part (b) Wind Variables**

| Symbol | Variable Name | Units | Variable Definition |
|---|---|---|---|
| $U$ | spdz | $ms^{-1}$ | Horizontal scalar wind speed (0.1, ±0.1) |
| $\sigma_u$ | sdspdz | $ms^{-1}$ | Standard deviation of wind speed |
| $\bar{U}$ | avgspdz | $ms^{-1}$ | 24-h average wind speed |
| $U_{mx}$ | mxgstz | $ms^{-1}$ | Maximum instantaneous wind gust |
| $t_{mx}$ | tgstz | hhmm | Time of occurrence of maximum gust |
| $U_{mx1}$ | mx1gst | $ms^{-1}$ | Maximum 1-min wind gust in 24 h based on non-overlapping 1-min averages |
| $t_{mx1}$ | t1gst | hhmm | Time of the maximum 1-min gust |
| $\theta$ | dirz | degrees | Unit vector mean wind direction (1, ±5, measured clockwise from true north) |
| $\sigma_\theta$ | sddirz | degrees | Standard deviation of wind direction fluctuations |
| $\theta_{mx}$ | dirgstz | degrees | Direction of the maximum gust |
| $\theta_{mx1}$ | dir1gst | degrees | Direction of the maximum 1-min gust |
| $w$ | wz | $ms^{-1}$ | Vertical velocity (0.1, ±0.1, positive upward) |
| $\sigma_w$ | sdwz | $ms^{-1}$ | Standard deviation of the vertical velocity fluctuations about the mean |
| $u_*^2$ | fvel2 | $m^2s^{-2}$ | Friction velocity squared (0.1, **) $u_*^2 = -\overline{u'w'}$ = momentum flux per unit density, positive downward |

## Part (c) Atmospheric State Variables

| Symbol | Variable Name | Units | Variable Definition |
|---|---|---|---|
| $T$ | tempz | ˚C | Air temperature (0.1, ±0.3) |
| $T_{mx}$ | mxtemp | ˚C | Maximum instantaneous temperature |
| $t_{mx}$ | tmxtemp | hhmm | Time of maximum temperature |
| $T_{mn}$ | mntemp | ˚C | Minimum instantaneous temperature |
| $t_{mn}$ | tmntemp | hhmm | Time of minimum temperature |
| $T_{mid}$ | midtemp | ˚C | Midnight temperature (*laarc* and *wrarc* only) |
| $T'$ | | ˚C | Temperature fluctuation (not logged) |
| $p$ | press | mb | Atmospheric pressure (0.1, ±0.6) |
| $p_{mx}$ | mxpress | mb | Maximum instantaneous pressure |
| $p_{mn}$ | mnpress | mb | Minimum instantaneous pressure |
| $h$ | rh | % | Average relative humidity (1, ±10) |
| $\bar{h}$ | avgrh | % | 24-hr average relative humidity |
| $h_{mx}$ | mxrh | % | Maximum relative humidity |
| $h_{mn}$ | mnrh | % | Minimum relative humidity |
| $h_{mid}$ | midrh | % | Midnight relative humidity (*laarc* and *wrarc* only) |
| $T_d$ | dewp | ˚C | Dew point temperature (0.1, **)<br>$T_d = f(VP(h,SVP(T,h)))$, where $VP$ and $SVP$ are vapor pressure and saturation vapor pressure; when $T < 0$˚C, $T_d$ is the frost point |
| $\bar{T}_d$ | avgdewp | ˚C | 24-hr average dew point temperature |
| $T_{dmx}$ | mxdewp | ˚C | Maximum instantaneous dew point |
| $T_{dmn}$ | mndewp | ˚C | Minimum instantaneous dew point |
| $q$ | ah | g m$^{-3}$ | Absolute humidity (0.01, above 0˚C: 1.0˚C, below 0˚C: 1.5˚C [accuracies given by manufacturer after converting to $T_d$]) |
| $\bar{q}$ | avgah | g m$^{-3}$ | 24-hr average absolute humidity |
| $q'$ | | g m$^{-3}$ | Absolute humidity fluctuation (not logged) |
| $\rho$ | | kg m$^{-3}$ | Atmospheric density (kg m$^{-3}$, not logged)<br>$\rho = p/RT$, where $R$ is the gas constant for dry air (= 287 J kg$^{-1}$ K$^{-1}$), $p$ is pressure (mb), and $T$ is temperature (K) |

## Part (d) Precipitation-Related Variables

| Symbol | Variable Name | Units | Variable Definition |
|---|---|---|---|
| $r$ | precip | in | 15-min total precipitation, includes rain and melted frozen precipitation (0.01, ±0.01r) |
| $\hat{r}$ | tprecip | in | 24-hr total precipitation |
| $s_d$ | snowd | in | Snow depth (0.1, ±0.4) |
| $s_{dmid}$ | midsnowd | in | Midnight snow depth (0.1, ±0.4) |
| $s_f$ | snowf | in | Snowfall (0.1, ±0.4). Estimated from increases in snow depth when liquid precipitation, $r$, is being recorded. |

*Continued on next page*

| **Part (d)**—*Continued* | | | |
|---|---|---|---|
| **Symbol** | **Variable Name** | **Units** | **Variable Definition** |
| *l* | lstks | unitless | Number of lightning strokes in 15 min within a range that varies from a few km to approximately 50 km. A lightning "flash" may consist of 1 to 30 strokes, with four strokes being the average. |
| $\hat{l}$ | totlstks | unitless | Number of lightning strokes in 24-hr |

| **Part (e) Radiative Energy Fluxes** (Irradiances are measured with radiometers oriented horizontally.) | | | |
|---|---|---|---|
| **Symbol** | **Variable Name** | **Units** | **Variable Definition** |
| $K\downarrow$ | swdn | W m$^{-2}$ | Shortwave irradiance, or global radiation, includes diffuse and direct beam in the 0.285-µ to 2.800-µ waveband (1, ±0.035 $K\downarrow$ [zenith angle 0–70˚], ±0.065 $K\downarrow$ [zenith angle 70–90˚] watts m$^{-2}$, positive downward) |
| $\hat{K}\downarrow$ | swedn | MJ m$^{-2}$ | 24-h total shortwave radiative energy $K\downarrow = \int_0^{24} K\downarrow dt$ (0.01, **) |
| $K\uparrow$ | swup | W m$^{-2}$ | Reflected shortwave irradiance, positive upward |
| $\hat{K}\uparrow$ | sweup | MJ m$^{-2}$ | 24-h total reflected shortwave radiative energy $K\uparrow = \int_0^{24} K\uparrow dt$ |
| $L\downarrow$ | lwdn | W m$^{-2}$ | Long-wave atmospheric irradiance in the 3.5-µ to 50-µ waveband (1, ±0.06*$L\downarrow$, positive downward) |
| $\hat{L}\downarrow$ | lwedn | MJ m$^{-2}$ | Downward long-wave energy received in 24 hr $L\downarrow = \int_0^{24} L\downarrow dt$ (0.1, **), |
| $L\uparrow$ | lwup | W m$^{-2}$ | Terrestrial irradiance, positive upward |
| $\hat{L}\uparrow$ | lweup | MJ m$^{-2}$ | Upward long-wave energy received in 24 hr $L\uparrow = \int_0^{24} L\uparrow dt$ |
| $Q^*$ | netrad | W m$^{-2}$ | Net irradiance (1, **, positive downward) $Q^* = K\downarrow - K\uparrow + L\downarrow - L\uparrow$ |
| $\hat{Q}^*$ | nete | W m$^{-2}$ | 24-h net radiative energy received $Q^* = \int_0^{24} Q^* dt$ (0.1, **) |

| **Part (f) Eddy Fluxes of Heat** | | | |
|---|---|---|---|
| **Symbol** | **Variable Name** | **Units** | **Variable Definition** |
| $Q_h$ | sheat | W m$^{-2}$ | Sensible heat flux, produced by turbulence in the presence of a temperature gradient (1, **, positive upward) $Q_h = 1.08 C_p \overline{w'T_v'} + 0.1 Q_e$, where $C_p$ is the specific heat of dry air at constant pressure (= 1006 J kg$^{-1}$ K$^{-1}$ at 10˚C) |
| $\hat{Q}_h$ | sheate | MJ m$^{-2}$ | 24-h total sensible heat energy (0.01, **) $\hat{Q}_h = \int_0^{24} Q_h dt$ |
| $Q_e$ | lheat | W m$^{-2}$ | Latent heat flux, produced by turbulence in the presence of a gradient in the absolute humidity (1, **, positive upward) $Q_e = L\overline{w'q'}$ where $L$ is the latent heat of vaporization of water (≈ 2480 J g$^{-1}$ at approximate annual mean temperature of 46˚F) |
| $\hat{Q}_e$ | lheate | MJ m$^{-2}$ | 24-hr total latent heat energy (0.1, **) $\hat{Q}_e = \int_0^{24} Q_e dt$ Note: the evapotranspiration, $e$, in mm of water over the 24-hr period is given by $e = 1.45\ Q_e$ |

| **Part (g) Subsurface Measurements** | | | |
|---|---|---|---|
| **Symbol** | **Variable Name** | **Units** | **Variable Definition** |
| $Q_f$ | sflux | Wm$^{-2}$ | Subsurface soil heat flux (not archived) |
| $T_s$ | stempz | ˚C | Soil temperature (0.1, ±0.3) |
| $\chi_w$ | smoistz | % | Volumetric soil moisture content. For a given volume of soil, the volumetric soil moisture content is the percentage of that volume of soil that is water. |
| $\hat{\chi}_w$ | avgsmoist | % | 24-hr average soil moisture. |
| $Q_g$ | gheat | W m$^{-2}$ | Ground heat flux at the surface produced by a temperature gradient at the surface (1, ±0.05 $Q_g$, positive downward) |
| $\hat{Q}_g$ | gheate | MJ m$^{-2}$ | Soil heat flux at the surface $Q_g = Q_f + C\Delta z\left(\frac{\Delta T_s}{\Delta t}\right)$, where $\Delta z$ = 0.08 m, $\Delta t$ is 900 s and $C$ is the heat capacity. $C = f(\chi_w)$ |

| Part (h) Fuel Moisture | | | |
|---|---|---|---|
| **Symbol** | **Variable Name** | **Units** | **Variable Definition** |
| $W_{10}$ | fm10 | % | 10-hr fine dead fuel moisture (1, when FM10 = 0–12%: 1.9%, when FM10 =12–30%: 3.6%, when FM10 > 30%: 16%). $W_{10}$ is equal to the percent water (by weight) in a dead fuel of diameter < 1/4". |
| $W_1$ | fm1 | % | 1-hr fine dead fuel moisture, estimated from *fm10*. $W_1 = f(W_{10}, K\downarrow, T, h)$ |

**Table 13.4.** Meteorological Variables Measured with the Sodar

| Symbol | Variable Name | Units | Variable Definition |
|---|---|---|---|
| $u$ | | m s$^{-1}$ | East-west wind component, not archived |
| $v$ | | m s$^{-1}$ | North-south wind component, not archived |
| $U_s$ | spdz | m s$^{-1}$ | Horizontal vector wind speed (0.1, ** m s$^{-1}$) $U_s = \sqrt{u^2 + v^2}$ |
| $\theta_s$ | dirz | degrees | Vector wind direction (1, ** degrees, measured clockwise from true north) $\theta_s = f(u,v)$ |
| $\sigma_{\theta s}$ | sddirz | degrees | Standard deviation of wind direction fluctuations |
| $w_s$ | wz | m s$^{-1}$ | Vertical velocity (0.1, ** m s$^{-1}$) |
| $\sigma_{ws}$ | sdwz | m s$^{-1}$ | Standard deviation of vertical velocity fluctuations |
| $I$ | intz | unitless | Intensity of the echo received by the vertical antenna |

Table 13-5 contains measurement level, measurement height above ground, $z$, and the set of variables measured every 15 min at each of the six towers. Table 13-6 repeats Table 13-5 except for 24 hr data, and Tables 13-7 and 13-8 give information on 15 min and 24 hr surface and subsurface data.

**Table 13-5.** Meteorological Variables Measured (or Calculated) Every 15 min at Height $z$

| Level | z (m) | Wind | | | | | | | Atmospheric State | | | | | Precipita-tion | | | | Radiative Energy Fluxes | | | | | Eddy Fluxes | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | $u$ | $\sigma_u$ | $\theta$ | $\sigma_\theta$ | $w$ | $\sigma_w$ | $u_*^2$ | $T$ | $p$ | $h$ | $T_d$ | $q$ | $r$ | $s_d$ | $s_f$ | $l$ | $K\downarrow$ | $K\uparrow$ | $L\downarrow$ | $L\uparrow$ | $Q^*$ | $Q_h$ | $Q_e$ |
| **TA-6** | | | | | | | | | | | | | | | | | | | | | | | | |
| 4 | 92.0 | x | x | x | x | x | x | | x | | | | | | | | | | | | | | | |
| 3 | 46.0 | x | x | x | x | x | x | | x | | | | | | | | | | | | | | | |
| 2 | 23.0 | x | x | x | x | x | x | | x | | | | | | | | | | | | | | | |
| 1 | 11.5 | x | x | x | x | x | x | x | x | | | | x | | | | | | | | | | x | x |
| 0 | 1.2 | | | | | | | | x | x | x | x | | x | x | x | x | x | x | x | x | x | | |
| **TA-41** | | | | | | | | | | | | | | | | | | | | | | | | |
| 2 | 23.0 | x | x | x | x | x | x | | x | | | | | | | | | | | | | | | |
| 1 | 11.5 | x | x | x | x | x | x | | x | | | | | | | | | | | | | | | |
| 0 | 1.2 | | | | | | | | x | | | | | | | | | x | | | | | | |
| **TA-49** | | | | | | | | | | | | | | | | | | | | | | | | |
| 3 | 46.0 | x | x | x | x | x | x | | x | | | | | | | | | | | | | | | |
| 2 | 23.0 | x | x | x | x | x | x | | x | | | | | | | | | | | | | | | |
| 1 | 11.5 | x | x | x | x | x | x | | x | | | | | | | | | | | | | | | |
| 0 | 1.2 | | | | | | | | x | | x | | | x | | | | x | | | | | | |
| **TA-53** | | | | | | | | | | | | | | | | | | | | | | | | |
| 3 | 46.0 | x | x | x | x | x | x | | x | | | | | | | | | | | | | | | |
| 2 | 23.0 | x | x | x | x | x | x | | x | | | | | | | | | | | | | | | |
| 1 | 11.5 | x | x | x | x | x | x | | x | | | | | | | | | | | | | | | |
| 0 | 1.2 | | | | | | | | x | | x | x | | x | | | | x | | | | | | |
| **TA-54** | | | | | | | | | | | | | | | | | | | | | | | | |
| 3 | 46.0 | x | x | x | x | x | x | | x | | | | | | | | | | | | | | | |
| 2 | 23.0 | x | x | x | x | x | x | | x | | | | | | | | | | | | | | | |
| 1 | 11.5 | x | x | x | x | x | x | x | x | | | | x | | | | | | | | | | x | x |
| 0 | 1.2 | | | | | | | | x | x | x | x | | x | | | | x | x | x | x | x | | |
| **Pajarito Mountain** | | | | | | | | | | | | | | | | | | | | | | | | |
| 1 | 36.6 | x | x | x | x | | | | x | | | | | | | | | | | | | | | |
| 0 | 2.0 | | | | | | | | x | x | x | x | | x | x | x | | | | | | | | |

**Table 13-6**. Meteorological Variables Measured (or Calculated) Every 24 hr at Height *z*

| Level | z (m) | Wind | | | Atmospheric State | | | | | | Precpita-tion | | | Radiative Energy | | | | | Heat Energy | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | $\overline{u}$ | $u_{mx}$ $\theta_{mx}$ $t_{mx}$ | $u_{mx1}$ $\theta_{mx1}$ $t_{mx1}$ | $T_{mx}$ $t_{mx}$ | $T_{mn}$ $t_{mn}$ | $p_{mx}$ $p_{mn}$ | $\overline{h}$ $h_{mx}$ $h_{mn}$ | $\overline{T_d}$ $T_{dmx}$ $T_{dmn}$ | $\overline{q}$ | $\hat{r}$ | $\hat{s}_f$ | $\hat{l}$ | $\hat{K}\downarrow$ | $\hat{K}\uparrow$ | $\hat{L}\downarrow$ | $\hat{L}\uparrow$ | $\hat{Q}^*$ | $\hat{Q}_h$ | $\hat{Q}_e$ |
| **TA-6** | | | | | | | | | | | | | | | | | | | | |
| 4 | 92.0 | x | x | | | | | | | | | | | | | | | | | |
| 3 | 46.0 | x | x | | | | | | | | | | | | | | | | | |
| 2 | 23.0 | x | x | | | | | | | | | | | | | | | | | |
| 1 | 11.5 | x | x | x | | | | | | x | | | | | | | | | x | x |
| 0 | 1.2 | | | | x | x | x | x | x | | x | x | x | x | x | x | x | x | | |
| **TA-41** | | | | | | | | | | | | | | | | | | | | |
| 2 | 23.0 | x | x | | | | | | | | | | | | | | | | | |
| 1 | 11.5 | x | x | x | | | | | | | | | | | | | | | | |
| 0 | 1.2 | | | | x | x | | | | | | | | x | | | | | | |
| **TA-49** | | | | | | | | | | | | | | | | | | | | |
| 3 | 46.0 | x | x | | | | | | | | | | | | | | | | | |
| 2 | 23.0 | x | x | | | | | | | | | | | | | | | | | |
| 1 | 11.5 | x | x | | | | | | | | | | | | | | | | | |
| 0 | 1.2 | | | | x | x | | x | | | x | | | x | | | | | | |
| **TA-53** | | | | | | | | | | | | | | | | | | | | |
| 3 | 46.0 | x | x | | | | | | | | | | | | | | | | | |
| 2 | 23.0 | x | x | | | | | | | | | | | | | | | | | |
| 1 | 11.5 | x | x | x | | | | | | | | | | | | | | | | |
| 0 | 1.2 | | | | x | x | | x | x | | x | | | x | | | | | | |
| **TA-54** | | | | | | | | | | | | | | | | | | | | |
| 3 | 46.0 | x | x | | | | | | | | | | | | | | | | | |
| 2 | 23.0 | x | x | | | | | | | | | | | | | | | | | |
| 1 | 11.5 | x | x | x | | | | | | x | | | | | | | | | x | x |
| 0 | 1.2 | | | | x | x | x | x | x | | x | x | | x | x | x | x | x | | |
| **Pajarito Mountain** | | | | | | | | | | | | | | | | | | | | |
| 1 | 36.6 | x | x | x | | | | | | | | | | | | | | | | |
| 0 | 2.0 | | | | x | x | x | x | x | | x | x | | | | | | | | |

**Table 13-7.** Surface and Subsurface Variables Measured (or Calculated) Every 15 min at Height or Depth *z*

| z (m) | $Q_g$ | $\chi_w$ | $T_s$ | $W_{10}$ | $W_1$ |
|---|---|---|---|---|---|
| **TA-6** | | | | | |
| 0.30 | | | | x | x |
| 0.00 | x | | | | |
| -0.02 | | | x | | |
| -0.06 | | | x | | |
| 0 to -0.08 | | x | | | |
| -0.10 | | | x | | |
| 0 to -0.15 | | x | | | |
| **TA-54** | | | | | |
| 0.30 | | | | | |
| 0.00 | x | | | | |
| -0.02 | | | x | | |
| -0.06 | | | x | | |
| 0 to -0.08 | | x | | | |
| -0.10 | | | x | | |
| 0 to -0.15 | | x | | | |

**Table 13-8.** Surface and Subsurface Variables Measured (or Calculated) Every 24 hr at Height or Depth *z*

| z (m) | $\hat{Q}_g$ | $\overline{\chi}_w$ |
|---|---|---|
| **TA-6** | | |
| 0.00 | x | |
| -0.02 | | |
| -0.06 | | |
| 0 to -0.08 | | x |
| 0 to -0.15 | | x |
| **TA-54** | | |
| 0.00 | x | |
| -0.02 | | |
| -0.06 | | |
| 0 to -0.08 | | x |
| 0 to -0.15 | | x |

### c. Sampling

The 15-min sampling period recommended by the DOE “Environmental Regulatory Guide” is used throughout the network. This period is long enough to give good estimates of both mean and turbulence quantities when conditions are fairly steady, yet it is short enough to provide adequate temporal resolution during periods of change for emergency response modeling.

The time associated with each datum is the ending time in MST of the standard 15-min sampling period; for example, HH15, HH30, HH45, and HH00. All maxima, minima, and other 24-h summary values are based on the 0000–2400 MST period.

The sampling rate for most primary variables and their standard deviations is 0.33 Hz, or one sample every 3 s. This rate results in a 15-min sample size of 300, which is large enough to estimate means to ±5%. The standard deviation of the vertical velocity is underestimated by 15% during the day and 25% during the night because of the propeller’s slow response. For the event-driven signals, such as precipitation and lightning, the 0.33-Hz sampling rate does not apply.

The sampling rate of the fuel moisture is one sample every minute for a total of 15 samples for every 15-min period. This smaller sample rate is recommended by the manufacturer and is suitable because of the slow nature of change in the fuel moisture of a 10-hr fuel stick. The sampling rate for the subsurface measurements is one sample every 10 s.

Maxima and minima are generally based on data collected at the 0.33-Hz sampling rate. The exception is the 1-min wind gust, which is based on non-overlapping 1-min averages. The maximum instantaneous wind gust is actually a 1- to 2-s average gust because of the instrument’s limited response. Slow instrument response also affects the extremes of temperature, pressure, and relative humidity.

The covariances used to estimate the eddy fluxes of heat, moisture, and momentum are computed from data sampled at a 2-Hz rate, which results in a sample size of 1800. This sample size, obtained by using the recently installed sonic anemometers, gives flux estimates to within ±5%. Eddy flux data archived before 1998 were derived from vertical winds measured by propellers, and the slow response of the propellers caused an underestimation of the fluxes. Experiments suggest that using a propeller for flux measurement causes the sensible heat flux to be underestimated by 15%, the latent heat (moisture) flux to be underestimated by 10%, and the momentum flux to be underestimated by 30% (Stone et al. 1995).

Sodar data represent spatial as well as temporal averages of the wind. The sodar samples the wind in twenty-three 30-m, non-overlapping layers from 65 m to 781 m above the ground. The height associated with each measurement is the midpoint of the layer, and the time is the ending time (MST) of the 15-min sampling period. Reported values are based on a maximum of 54 samples during the sampling period (1 every 16.7 s). Often, the sample size is less than 54, especially at the upper levels, because the system rejects data when the signal-to-noise ratio falls to some threshold value. On average, data recovery is 97% at 90 m above ground level (AGL), 60% at 510 m AGL, and 20% at 720 m AGL.

## *2. Data Management*

### a. Description of the Data Management Component

The data management component of the program controls the processing of the data from data loggers to its permanent archive and the automatic construction of graphics and tables. These end products are then made available on the Weather Machine, a service that is highly visible to the Laboratory staff, so the program is often judged by its data management component.

The data management objectives are to (1) maintain a secure, accessible, high-quality data archive and (2) deliver data, statistical summaries, graphics, special data sets, and other weather products to a large customer base as efficiently as possible. A significant portion of the program's resources have been devoted to fulfilling these objectives, including a substantial investment in personnel, hardware and software, and maintenance contracts.

Standards for data management follow guidance when applicable, such as in the calculation of turbulence quantities (EPA 1987), wind vector quantities (EPA 1987), stability categories (EPA 1978), and the formatting of model input files (EPA 1987).

Improvements in the data management component during the mid 1990s have increased the program's visibility, improved accessibility to the data for customers, increased usage of the data, and increased the overall efficiency of the program. Significant changes include the establishment of a Web site (the Weather Machine) in 1993, the development of a local binary data archive and software to move data to and from this archive (1995), creating a common gateway interface (CGI) feature for the Weather Machine for distributing data (1996), and the addition of several graphics packages for such products as wind roses, annual summaries, and monthly summaries (1996 and 1997).

### b. Hardware and Software

The program operates three Hewlett-Packard (HP) workstations, five x-terminals to access the workstations, a host of Campbell Scientific, Inc. (CSI) data loggers, two IBM personal computers (PCs) used for the sodar, and accompanying peripherals such as printers, external disks, and additional IBM and Macintosh PCs. The program also uses the Laboratory's Integrated Computing Network Common File System (ICN CFS), and the Laboratory network, LANLnet. Figure 13-4 shows these hardware components and the associated linkages.

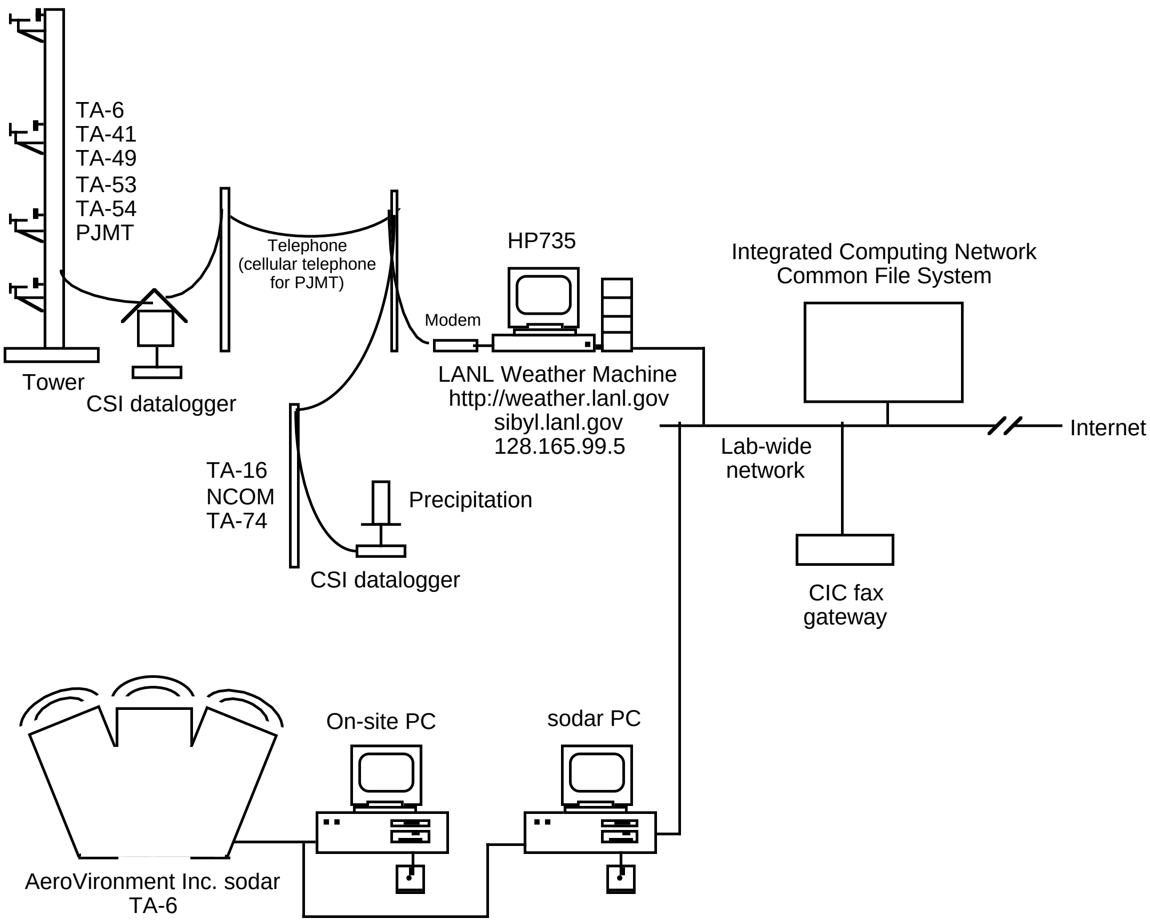


**Figure 13-4.** Main hardware components used in acquiring and processing meteorological data.

The program relies on several software packages, installed primarily in Hewlett-Packard's UNIX operating system, HP-UX (version 10.01). Below is a list of the software tools used by the program:

- **Cron** is a UNIX utility that runs all the automatic processes.
- **Shell scripts** consist of a series of UNIX commands. Shell scripts are run by cron and control all routine, periodic data processing by calling C language executables and PV-Wave executables.
- **C** language processes execute to convert data logger data to binary data, allow access to binary data, perform data requests from the Web page, and construct model input data files.
- **PV-Wave** is a programming language designed for visual data analysis. PV-Wave generates all routine graphical data displays for the Weather Machine and is used by the program staff to perform data analysis.

- **Perl** is a text processing language used in CGI applications. Perl scripts serve hypertext markup language (HTML) forms in Web browsers and pass information to and from clients. Perl is used by the program to manage raw data request forms and model input request forms on the Web page, along with other functions requiring text processing.
- **Apache Web Server** is the software used to run the Weather Machine Web server.
- **Campbell Scientific Datalogger programming language** is used by data loggers to control sampling, perform signal conditioning, and carry out initial processing (such as the computation of means, variances, and daily totals).
- **Telcom** software communicates with the Campbell Scientific, Inc., data loggers. Telcom only runs in a PC environment, requiring the use of SoftWindows.
- **SoftWindows** is the UNIX software used to emulate a PC environment to allow Telcom to execute.

### c. Routine Data Acquisition and Processing

In 1996 the binary data format replaced the 80-column textual format as the primary form of data archiving. All routinely processed data are placed into binary format files for storage, and other special, nonroutine data sets are also placed into binary files when possible.

The data record for each station consists of a series of annual binary files and a 90-day circular binary file for the 15-min data; similarly, the 24-hr data are stored in annual files and a 90-day circular file. Data in the circular files are checked weekly for quality and then are moved to the annual files. Thus the annual files contain only data that have been thoroughly checked and edited. Both circular and archive files are accessible through the CGI interface on the Weather Machine.

Data acquisition and processing operations are performed at regular intervals on several different time cycles. Below is an outline of these operations. All operations in the outline are automated except for the weekly, monthly, and annual tasks, which are performed manually.

1. On a 15-min cycle, cron
    - runs a script that invokes SoftWindows and Telcom, the data loggers are called (except Pajarito Mountain), and the latest data are transferred from the data loggers to the workstation Sibyl;
    - runs a script that converts data logger files to UNIX files;
    - calls a C language executable that reads the UNIX files, compares the data with expected ranges, and writes the data to binary circular files (data values falling outside predetermined ranges are entered as –999999);
    - runs scripts that run PV-Wave executables that read the binary circular files and update graphical and tabular summaries of current conditions; and
    - runs a script that runs a C language executable that uses the binary files to provide data to the Meteorological Information and Dispersion Assessment System (MIDAS) (see Section 4).

2. On an hourly cycle (from 0700–1500 MST only), cron performs the same operations as for the 15-min cycle in calling the cellular phone at the Pajarito Mountain station. The Pajarito Mountain station is called hourly from 0700–1500 MST to reduce cellular phone charges, but a special utility can be invoked to call the Pajarito Mountain station every 15 min during emergency situations.

3. On a 24-h cycle, cron
   - calls a script that runs PV-Wave executables that generate tabular and graphical summaries for the previous day and
   - runs a script that sends E-mail to the program staff concerning the status of data collection and range checking for the previous day.

4. Weekly,
   - data collected during the previous week are reviewed,
   - the circular files are edited, and
   - the binary archive files are updated by moving data from the station circular files to their archive files.

5. Monthly,
   - a PV-Wave executable is run to summarize the previous month's weather, and
   - a PV-Wave executable is run to update the daily and monthly extremes table.

6. In January, PV-Wave executables are run that construct annual weather summaries and wind roses for the previous year for the Laboratory's Environmental Surveillance Report.

In addition to processing data from the local meteorological network, program software

- automatically retrieves meteorological data from other Web sites,
- analyzes the system status and log files
- automatically handles raw data requests and model input data requests to the Weather Machine, and
- faxes weather forecasts to clients.

Figure 13-5 shows the locally constructed software components that control flow from the original raw data measurements to the final products. MDM.out, a C executable, controls flow to and from binary files and supports data requests to the Weather Machine. MS.out and STAR.out handle model input data requests. PV-Wave is used for producing routine summaries and graphics, as well as for special analyses.

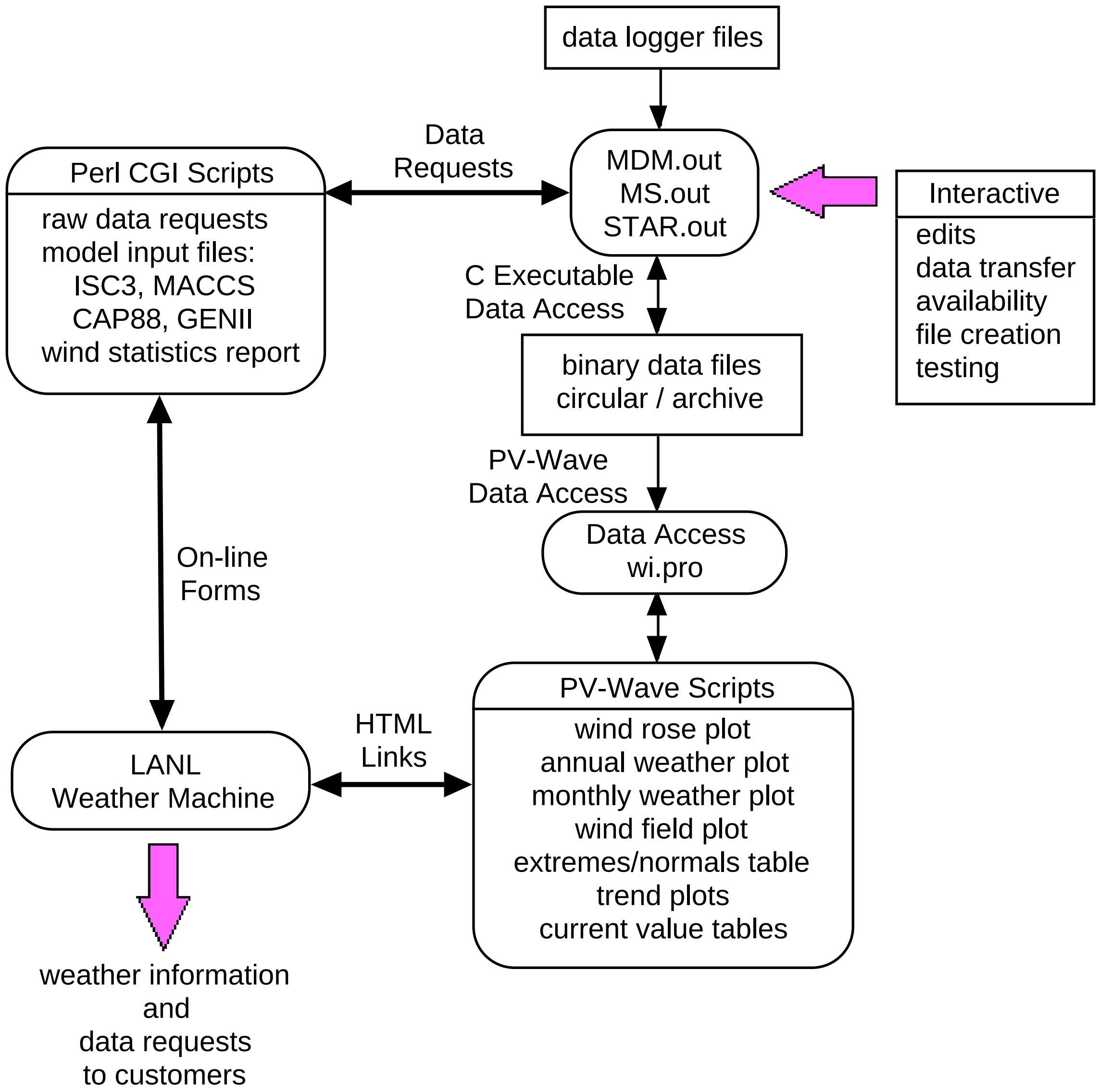


**Figure 13-5.** Main software components that control the flow of raw data from raw data files to the formatted products.

**d. Special Topics**

***The LANL Weather Machine***

The LANL Weather Machine (http://weather.lanl.gov), an Internet Web site, was established in 1993 as a means of distributing the tables and plots already in use for quality assurance and for emergency response applications. The Weather Machine has now developed into a useful tool for servicing routine data requests, providing information to the local weather-curious, promoting positive public relations, and making an extensive data set more accessible.

The Weather Machine provides a variety of meteorological data, including local weather information, weather forecast products, regional and national weather information, and local climatological data. On-line documentation is accessible, making the Weather Machine a stand-alone meteorological service.

Also included in the Weather Machine are data request forms that provide access to the raw data archive and model input files for some of the frequently used atmospheric dispersion and dose assessment models (ISC3, MACCS, CAP88, and GENII). The actual data request forms are in an HTML format, and the data can be downloaded directly into a spreadsheet. The forms are constructed depending on data availability and user-specified information.

The users of the Weather Machine consist of internal Laboratory employees, DOE laboratories, universities, and the public sector. Since its inception, usage of the Weather Machine has grown to about 1200 connections per laboratory workday. Raw-data requests on the Weather Machine average about 230 per quarter, and model data requests average about 36 per quarter. As the usage of the Weather Machine has increased, the staff time required to provide meteorological information has declined sharply.

### *Forecast Faxing*

Area forecasts, or "zone forecasts," are automatically faxed or E-mailed up to three times a day, seven days a week, to a variety of customers, including the Laboratory's Emergency Management and Response Group (FSS-20), Los Alamos County organizations, schools, and other requesting contractors. This cron-driven function uses a perl script to retrieve the zone forecasts from the Ohio State University weather gopher and send them by E-mail or fax, through the Laboratory's Computing, Information, and Communications (CIC) Division Fax Gateway.

### *Sodar Data*

Sodar data processing currently takes place outside of the automated tower site data processing. Sodar data are saved onto removable cartridges at the sodar site (TA-6), which are periodically transferred manually to the HP-735 workstation. The C executable, MDM.out, then converts the raw sodar data files to annual binary files, which are accessible with wi.pro in a manner similar to that used for other tower station files.

### *MIDAS*

The program supports emergency management at the Laboratory by maintaining the software used to calculate air concentrations of hazardous materials, if they are released to the atmosphere. This proprietary software, called MIDAS, is discussed in Section 4. Special features of the system that are related to the data management aspects of the program include

- maintenance of the backup UNIX workstation, Cass, in the emergency operations center;
- real-time transfer of meteorological data from the program's binary files to the MIDAS input files;

- ensuring compatibility between HP-UX and all components of the MIDAS system, which includes TGRAF (a Tektonix emulator) and InFoCAD (a geographical information system); and
- software that controls the transfer of local MIDAS plume maps to the emergency operations center for display.

### *3. Analysis*

Some program customers require more than access to raw meteorological data or standard summaries. Sometimes what is needed is an interpretation of the raw data, the computation of special quantities, or even the measurement of special meteorological variables. The analysis component of the program serves to fill this need.

Extensive analysis of the early tower data was conducted by Bowen in the mid to late 1980s, culminating in the document "Los Alamos Climatology" (Bowen 1990). Shortages in staffing led to a lull in analysis until the mid 1990s, when analysis again was feasible due to the addition of a staff member and improvements in data management. During this time many memorandums, reports, and draft reports were completed that aided in the understanding of the local meteorology of the Los Alamos area. A bibliography of local meteorological analysis studies can be found in a memorandum by Stone and Baars (1998).

Weather forecasting is another type of analysis performed by the program. Forecasts are used primarily in the winter when snow storms affect construction projects, road crew scheduling, school busing, and airport operations. Forecasts also support emergency response operations, explosives testing, and aerial photography campaigns. Because of limited resources for this activity, the program's policy is to make forecast information available on the Weather Machine and to automatically disseminate NWS zone forecasts to a list of requesters. Only when snow storms threaten do program staff develop their own forecasts.

### *4. Modeling*

The primary purpose of conducting meteorological monitoring at DOE sites is to maintain a plume modeling capability in support emergency planning and response. For many years the program provided this service using simple, straight-line Gaussian plume models. These models were deemed inadequate because they did not account for the Laboratory's complex terrain, multiple facilities, and numerous hazardous materials and because they did not automatically use measured winds or provide a map-based output.

The Meteorological Information and Dispersion System (MIDAS), which was purchased in 1993, markedly improved the program's modeling capabilities and also brought the Laboratory into compliance with DOE Order 151.1 (DOE 1995). The system consists of a radiological version (R-MIDAS) and a chemical version (C-MIDAS). The rationale for choosing the MIDAS model over other available models at the time is given in Stone and Dewart 1992.

MIDAS is a segmented plume model, or "puff" model. MIDAS releases a series of puffs with concentrations calculated according to the release rate at the time of the release. The trajectory of each individual puffs is calculated according to the real-time measured wind field, with updates in the winds being incorporated into the calculation every 15 min as new tower data are acquired. In this way spatial and temporal variations in winds are taken into account by the model. The growth of the individual puff is controlled by the stability, which is based on measured standard deviations of wind direction fluctuations. MIDAS also uses locally measured precipitation for a washout algorithm and uses temperature and insolation for modeling plume rise and for modeling evaporation from a chemical spill.

The wind field is automatically constructed from 11.5 m winds from the four mesa-top towers using a simple $1/r^2$ interpolation scheme. A standard power law relationship governs the extrapolating of wind speed to reference heights that are higher or lower than 11.5 m, and wind direction is assumed to not change in the vertical.

The model is not prognostic in the sense that wind fields are forecast and used to predict the resulting effect on the plume location. Projections of plume location provided by MIDAS are calculated by assuming persistence in the current wind field.

MIDAS is based on the idea that good emergency response relies on good emergency planning. Data used to calculate plumes in emergency situations come from predefined scenarios that were originally created for all medium- and high-risk facilities by the Facility Risk Management Group (ESH-3). Scenario information includes such data as type of material released, release rates of material, duration of release, and sensible heat rate in release (for fires). MIDAS also stores information about the materials themselves, as well as about buildings for which scenarios exist.

MIDAS is relatively easy to use, even for those with little training on the model. In an emergency, the user selects the location of the accident, the scenario that most closely resembles the accident, and the time of occurrence of the accident, and a plume calculation is produced in 30 to 100 s. Interpretation of the results and the use of the advanced capabilities of the model requires an experienced user, however. Determining how realistic results are in a meteorological sense requires a strong background in meteorology. Modifying scenario input parameters during an emergency, such as using manually entered meteorology, changing the location of the release, or changing the release rate for a given scenario, requires more advanced training in the use of the model.

Output from MIDAS includes a variety of text and map products. The most important MIDAS output is probably the graphic showing the estimated plume superimposed on a Laboratory map. The plume is shown as contours of concentration, given in terms of relevant emergency response thresholds (emergency response planning guidelines, or ERPGs, for C-MIDAS, millirems [mrem] for R-MIDAS). A zoom feature and a concentration-at-a-point feature are included with this map.

Figure 13-6 shows an example of plume-on-map output from C-MIDAS. In this example a hypothetical chorine release is simulated from TA-03 building 476. Contours are shown for ERPG-2 and ERPG-3 values, with the dark shading at the base of the plume denoting the current location of ERPG-3 concentrations, the narrow band of shading behind the base showing the current location of ERPG-2 concentrations, the third band of shading giving the 10-min projection of the location of ERPG-2 concentrations, and the lightest shading showing the 20-min projection of the location of ERPG-2 concentrations. For this scenario, chlorine is released as a liquid, and chlorine vapor is evaporated from the liquid pool at a rate estimated by an evaporation algorithm based on the work of Havens and Spicer (1985).

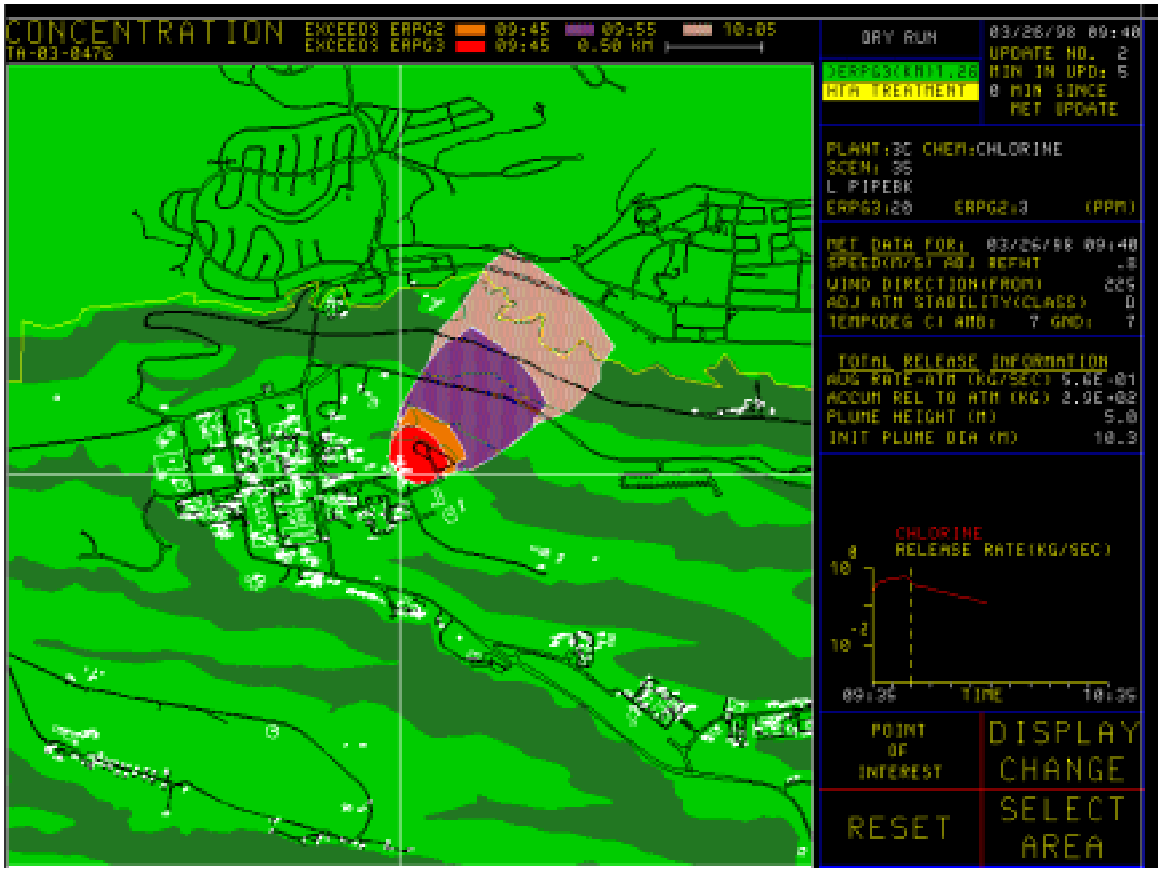


**Figure 13-6.** Example C-MIDAS output for hypothetical chlorine release from TA-03 building 476.

Figure 13-7 shows an example plume-on-map output from R-MIDAS. For this example, a hypothetical criticality accident is simulated from TA-18 building 168. Contours are given in mrem. This example shows how MIDAS takes into account spatial and temporal effects of the local wind field.

Limitations and uncertainties with MIDAS are typical of those associated with a model of this type. For instance, projections are based on the persistence of the wind field, so when winds are light and variable, there are large uncertainties in the results. Also, flows in the canyons are not accounted for and azimuthal shear in the vertical is not taken into account.

Extensive studies have been performed on models of the MIDAS type. One such study for surface releases in complex terrain was performed in 1980 and 1981 during the atmospheric studies in complex terrain (ASCOT) study (Dickerson and Gudiksen 1984). When comparing the model results with actual measurements, the study found that models of the MIDAS type predict concentrations within a factor of five 50% of the time and within a factor of 10 about 60% of the time.

When appropriate, program meteorologists also use the EPIcode, Archie, and HOTSPOT models. These models are straight-line Gaussian plume models, and they do not take advantage of the real-time measured wind field.

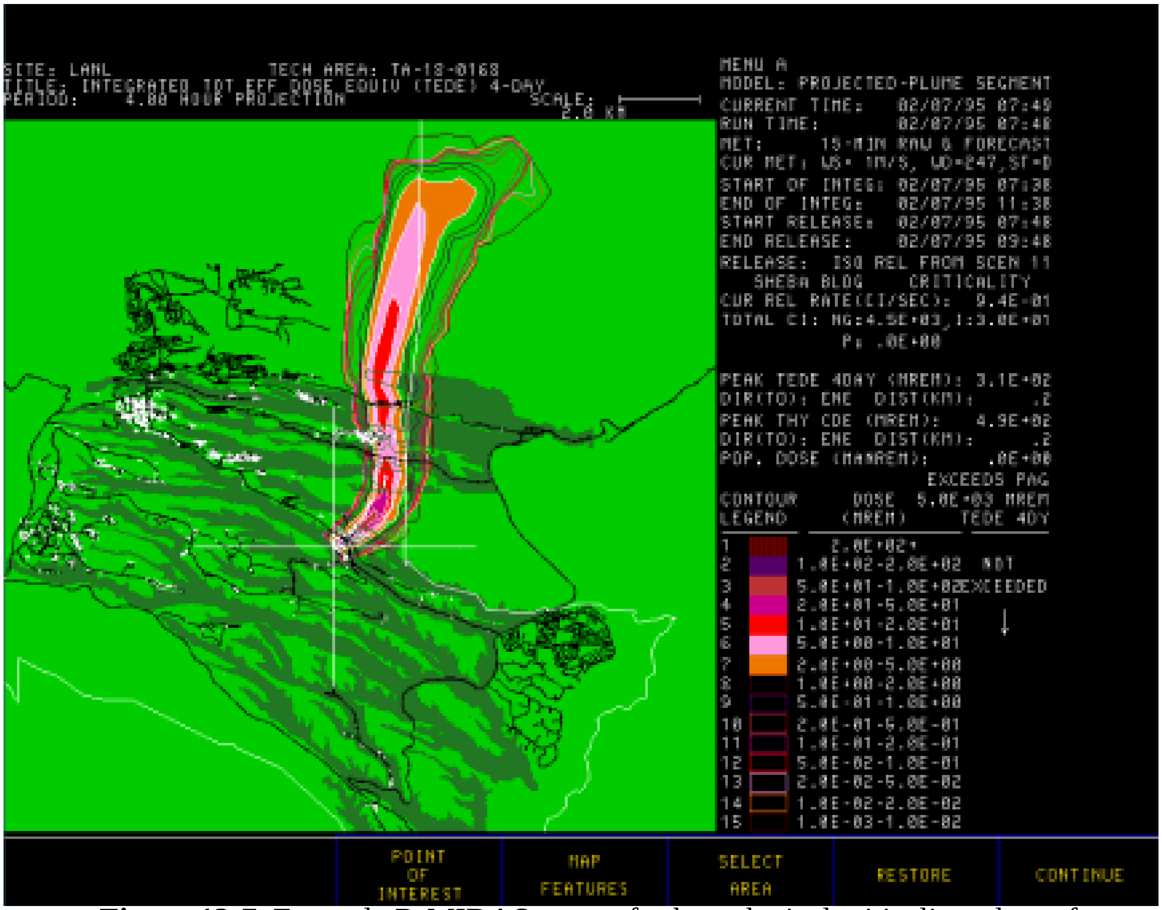


**Figure 13-7.** Example R-MIDAS output for hypothetical criticality release from TA-18 building 168.

### *5. Program Changes Since 1996 EMP*

#### a. Measurements

- The Pajarito Mountain station was added to the network.
- The 10-hr fuel moisture instrumentation was installed.
- Improved methods for measuring subsurface variables were implemented. See Stone 1998b for details.
- Data acquisition from the TA-16 and North Community precipitation stations was automated.
- Sonic anemometers for eddy flux measurements were installed at TA-6 and TA-54.

#### b. Data Management and Computer Hardware

- The HP-715 UNIX workstation Cass was installed in the emergency operations center (EOC) and configured as a backup for Sibyl.
- Snowfall and snow depth measurements were automated at TA-6 and Pajarito Mountain.
- Migration to the binary file system was completed.

- The NWS call-in was partially automated.
- All precipitation data stored in hard copy form was converted to electronic form.
- Improvements in the way MIDAS plume maps were transferred from the HP-735 to the Sun computer have been completed.
- Data access was improved through the creation of the program wi.pro.
- An automatic snowfall calculation program, snowfall.pro, was completed.
- Several routine products produced by the project were automated: time series plots for quality control, wind rose plots, monthly summary plot, annual summary plot, and wind field plot

The LANL Weather Machine has been improved by

- adding HTML forms for requesting raw data and model input files;
- making model output files for the codes ISC3, MACCS, CAP88 and GENII available from a data request form;
- setting up a hypertext transfer protocol (HTTP) server;
- reorganizing the home page;
- adding a wind field display;
- adding monthly summary plots; and
- adding climatological norms and extremes.

**c. Analysis**

- Results of the 1994 eddy flux comparison experiment is in draft form (Stone et al. 1995).
- A mixing depth estimation study was completed (Baars 1997).
- A study on the effect of nocturnal wind shear on pollutant transport was completed (Bowen et al. 1997).
- Evapotranspiration data were analyzed, and a report was drafted.
- A method for estimating 1-hr fuel moisture from a 10-hr fuel moisture measurement was determined.
- The program supported and participated in studies of local and regional winds in collaboration with the Laboratory’s Atmospheric and Climatic Sciences Group (EES-8). The studies included analyses of canyon flows and the relationship between the near-surface wind over the Pajarito Plateau and winds at the regional scale (report in progress).
- An analysis of the assumption of persistence in modeling plume trajectories was undertaken.
- Further analysis of the sodar’s performance was undertaken.

#### d. Modeling

- A draft of the MIDAS user's guide was completed.
- Scenarios were reviewed and revised to account for changes in operations.
- Several scenario updates were conducted.

#### e. Quality Assurance

- The Quality Assurance Project Plan was completed (Stone 1998a).

#### f. Formality of Operations

Formal or draft documents were developed that addressed the following topics:

- software documentation,
- the purpose and status of MIDAS scenarios,
- data processing procedures, and
- system management procedures.

## D. Quality Assurance and Quality Control

For complete documentation on the program's quality assurance and quality control, the reader is referred to the "Quality Assurance Project Plan," or QAPP (Stone 1998a). While some overlap exists between the QAPP and this document, the QAPP provides a thorough review of the program's mission, organizational structure, roles and responsibilities, and method of assuring quality.

## E. Anticipated Program Enhancements

The following changes and improvements are in various stages of planning or implementation. Within each program component, the order of tasks reflects current priorities. Because of the relatively small size of the program, the rate of progress on these tasks is sensitive to the demands of special projects.

Tasks for which completion seems certain by 2001 are indicated by the word "will" in the list below. Other tasks that may be in progress or completed by 2001 are indicated by the word "should."

#### a. Measurements

- All the data logger programs will be reprogrammed to correct the wind direction problem.

- The sodar system will be repaired or a new profiling instrument should be purchased and installed.

- The TA-74 precipitation station will be re-sited.

- Schematics will be completed for the TA-41 and TA-49 towers.

- The Pajarito Mountain precipitation station will be evaluated.

**b. Data Management and Computer Hardware**

- Data quality control should be automated.
- Telcom will be emulated on the UNIX platform.
- The Weather Machine will be improved by adding lightning data and snow depth data at TA-6.
- The Weather Machine should be improved by redesigning the home page, developing data acquisition and display for the sodar, and making raw data available in real time.

**c. Analysis**

- Some or all of Bowen’s climatology (Bowen 1990) will be updated.
- Snow depth data will be analyzed and the snowfall algorithm, snowfall.pro, will be assessed for its ability to estimate snowfall accurately.
- The cause of the deterioration of the sodar data should be determined, and a solution should be instituted.
- The surface energy balance should be analyzed, including analysis of the new ground flux measurements.
- Eddy flux data measured with a sonic anemometer will be compared with that gathered by the old method of measuring eddy fluxes using propeller-vane anemometers to characterize the old data.

**d. Modeling**

- Broader support for the MIDAS system should be established. This will involve identifying and training additional users of the system, preferably people with knowledge of industrial hygiene and health physics.
- The MIDAS system will be upgraded.
- The MIDAS base map should be converted to ArcView, and the map should be updated.
- C-MIDAS should be improved.
- The scenario strategy will be revised.

**e. Quality Assurance**

- The precipitation data from North Community and White Rock Y (TA-74) should be quality checked.

**f. Formality of Operations**

- System management procedures will be documented.
- The MIDAS user's guide will be completed.
- Station documentation will be completed.
- Documentation of supplemental data sets will be completed.

## F. References


Baars 1997: J. A. Baars, "Mixing Depth Estimation at Los Alamos: a Preliminary Investigation," Los Alamos National Laboratory document LA-UR-97-366.

Bowen 1990: B. M. Bowen, "Los Alamos Climatology," Los Alamos National Laboratory report LA-11735-MS (May 1990).

Bowen 1992: B. M. Bowen, "Los Alamos Climatology Summary Including Latest Normals from 1961–1990," Los Alamos National Laboratory report LA-12232-MS (March 1992).

Bowen et al. 1997: B. M. Bowen, J. A. Baars, and G. L. Stone, "Nocturnal Wind Direction Shear and Its Potential Impact on Pollutant Transport," Los Alamos National Laboratory document LA-UR-97-3746 (December 1997), (submitted to the *Journal of Applied Meteorology*).

Dickerson and Gudiksen 1984: M. H. Dickerson and P. H. Gudiksen, "Atmospheric Studies in Complex Terrain Technical Progress Report FY-1979 through FY-1983," Lawrence Livermore National Laboratory report UCID-19851 (ASCOT 84-1).

DOE 1990a: US Department of Energy, "General Environmental Protection Program," DOE Order 5400.1 (November 1988).

DOE 1990b: US Department of Energy, "Radiation Protection of the Public and the Environment," DOE Order 5400.5 (June 1990).

DOE 1991a: US Department of Energy, "Environmental Regulatory Guide for Radiological Effluent Monitoring and Environmental Surveillance," DOE publication DOE/EH-0173T (January 1991).

DOE 1991b: US Department of Energy, "Planning and Preparedness for Operational Emergencies," DOE Order 5500.3A (April 1991).

DOE 1995: US Department of Energy, "Comprehensive Emergency Management System," DOE Order 151.1 (September 1995).

EPA 1978: US Environmental Protection Agency, “Guideline on Air Quality Models,” EPA-450/2-78-027R.

EPA 1981: US Environmental Protection Agency, “On-site Meteorological Instrumentation Requirement to Characterize Diffusion from Point Sources,” EPA-600.9-81-C20 (April 1981).

EPA 1987: US Environmental Protection Agency, “On-Site Meteorological Program Guidance for Regulatory Modeling Applications,” EPA-450/4-87-013 (1987).

EPA 1989: US Environmental Protection Agency, “Quality Assurance Handbook for Air Pollution Measurement Systems: Volume IV. Meteorological Measurements,” EPA-600/4-82-060 (revised in August 1989).

Havens and Spicer 1985: J. A. Havens and T. O. Spicer, “Development of an Atmospheric Dispersion Model for Heavier-than-Air Gas Mixtures,” Vol. 1, report no. CG-D-23-85 (US Coast Guard, Office of Research and Development, Washington, D.C., 1985).

Lee et al. 1994: J. T. Lee, J. Archuleta, and D. Hoard, “Evaluation of a Diagnostic Wind Field Model for the Los Alamos Area,” Los Alamos National Laboratory document LA-UR-94-3587 (1994).

NWS 1989: National Weather Service, US Department of Commerce, “National Weather Service Observing Handbook No. 2, Cooperative Station Observations” (1989).

Stone 1998a: G. Stone, “Quality Assurance Project Plan for Meteorological Monitoring,” Los Alamos National Laboratory document (in press, April 1998).

Stone 1998b: G. Stone, “Notes on Measuring Soil Heat Flux Density,” Los Alamos National Laboratory memorandum ESH-17: 98-183 (April 1998).

Stone and Baars 1998: G. Stone and J. A. Baars, “Publications Based on Meteorological Observations made at the Los Alamos National Laboratory,” Los Alamos National Laboratory memorandum ESH-17:98-184 (April 1998).

Stone and Dewart 1992: G. Stone and J. Dewart, “Status of the Modeling Upgrade Project, Findings and Recommendations,” Los Alamos National Laboratory memorandum EM-8:92-1343 (May 1992).

Stone and Holt 1996: G. Stone and H. D. Holt, “Meteorological Monitoring at Los Alamos,” Los Alamos National Laboratory document LA-UR-95-3697.

Stone et al. 1995: G. Stone, D. Rand, and W. A. Olsen, “Eddy Flux Comparison Experiment” (in press, 1995).

Tower Systems, Inc. 1997: Tower Systems, Inc., “Inspection Reports for Los Alamos National Laboratory” (October 1997).